Introduction to Freescale's Latest Generation of Tire Pressure Monitoring System Solutions

APF-ACC-T0999

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J U N E . 2 0 1 5

External Use

Current Automotive Market Trends

- The connected vehicle and future autonomous vehicles
- Functionally safe and secure
- Efficiency desired: power, fuel, weight
- Chinese auto growth and influence of tier1 suppliers globally
  - Content per vehicle growth
  - Increasing pressure to **reduce time to market**
- Turn-key solutions becoming mandatory
  - Hardware and software integration
  - Complete easy-to-use development environment
- TPMS allows optimum tire inflation
  - Saves fuel consumption and reduces CO2 emissions
  - Saves lives to reach the zero fatalities goal

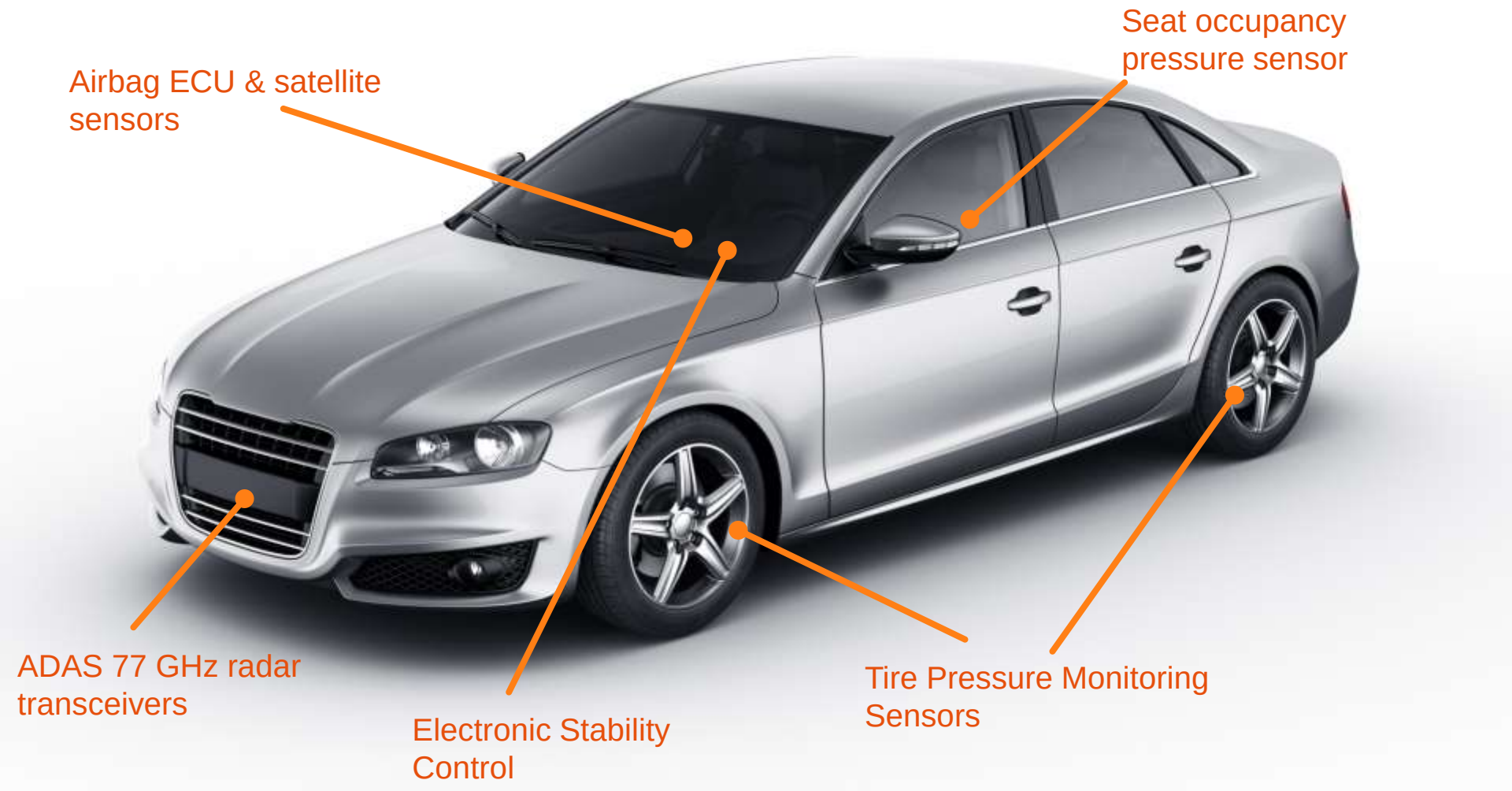
Enabling Self Driving Cars

- Transition from passive to active safety as radar becomes mainstream
- Possibility to link tire information with chassis and ADAS
- Increasing need for connected intelligent safety for cars that can’t crash
- Self parking to self-driving
- Utilize road vibration information for GPS alternate smoother routes, extending the life of your tires
- TPMS’ integrated wireless transmitters programmed to automatically call for help if you’re stranded with a flat, communicating your precise location and speeding their response time

TPMS Legislation Around the World

Region	Requirements
USA	Regulation from 2005: FMVSS138 mandates TPMS for new vehicles starting in **October 2005**
European Union	Regulation from 2012: EC661-2009 mandates TPMS starting Nov 2012 for new type approved vehicles and for all new vehicles starting in **November 2014**
South Korea / Japan	Regulation from 2013: TPMS vehicles to be installed on passenger cars from January 2013 for new models and **January 2015** for existing models
China	Recommended specification Enforcement standard in drafting stage. Draft has been done and submitted to the National Standard Committee **end of 2014.**
Taiwan	Standard published in Nov 2012 and to be implemented starting **November 2014**
Russia, Kazakhstan, Belarus (Eurasia)	Valid from **2015** onwards and replaces national legislation
Indonesia, Israel, Malaysia, Philippines, Turkey	Require European whole vehicle type approval for vehicles imported from Europe. As a consequence TPMS will be required for all new vehicles in **November 2014.**

Freescale Automotive Safety Solutions

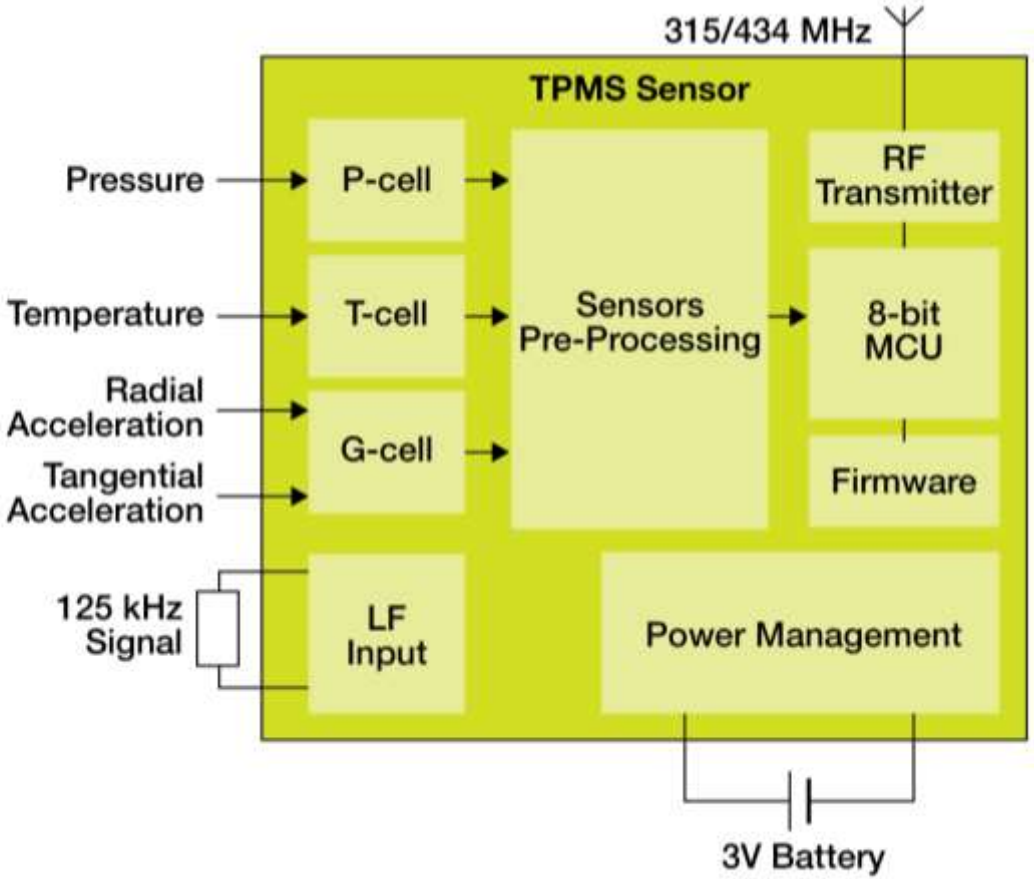


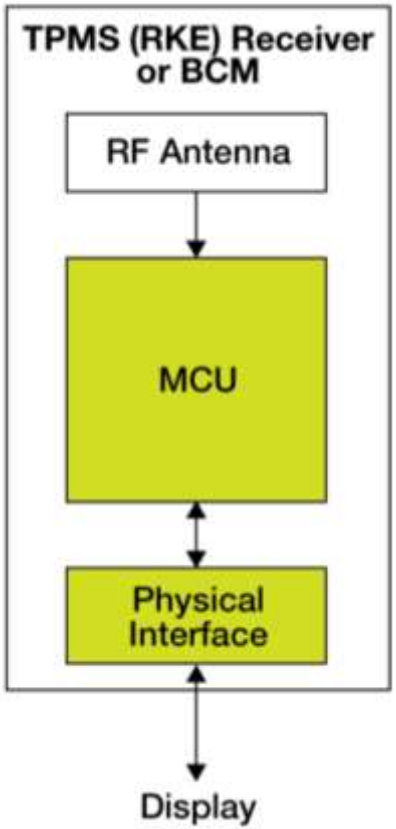
October 20th Press Release

Freescale introduces world's smallest integrated tire pressure monitoring

AUSTIN, Texas -- Freescale Semiconductor today introduced the FXTH87 tire pressure monitoring system (TPMS) family, which is the smallest integrated package TPMS solution available at an extremely light weight of 0.3 grams. The FXTH87 family is 50 percent smaller than competing products, helping designers reduce overall bill of materials costs. Freescale's newest TPMS system-in-package solution provides low power consumption combined with the highest level of functional integration in one package, featuring a dual-axis accelerometer architecture, pressure and temperature sensor, integrated MCU, RF transmitter and low frequency receiver

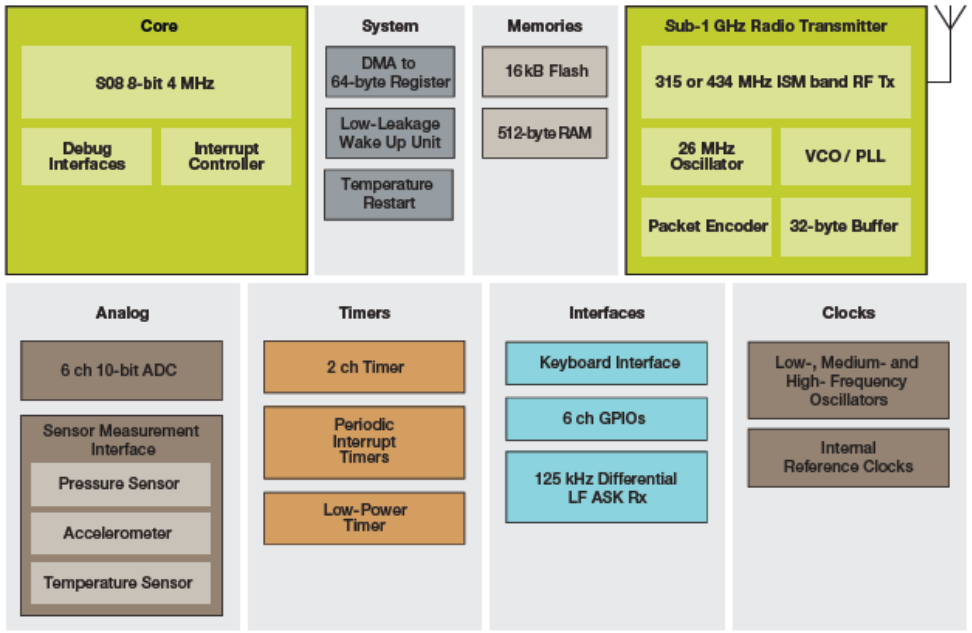
TPMS System Application Diagram





Freescale Technology

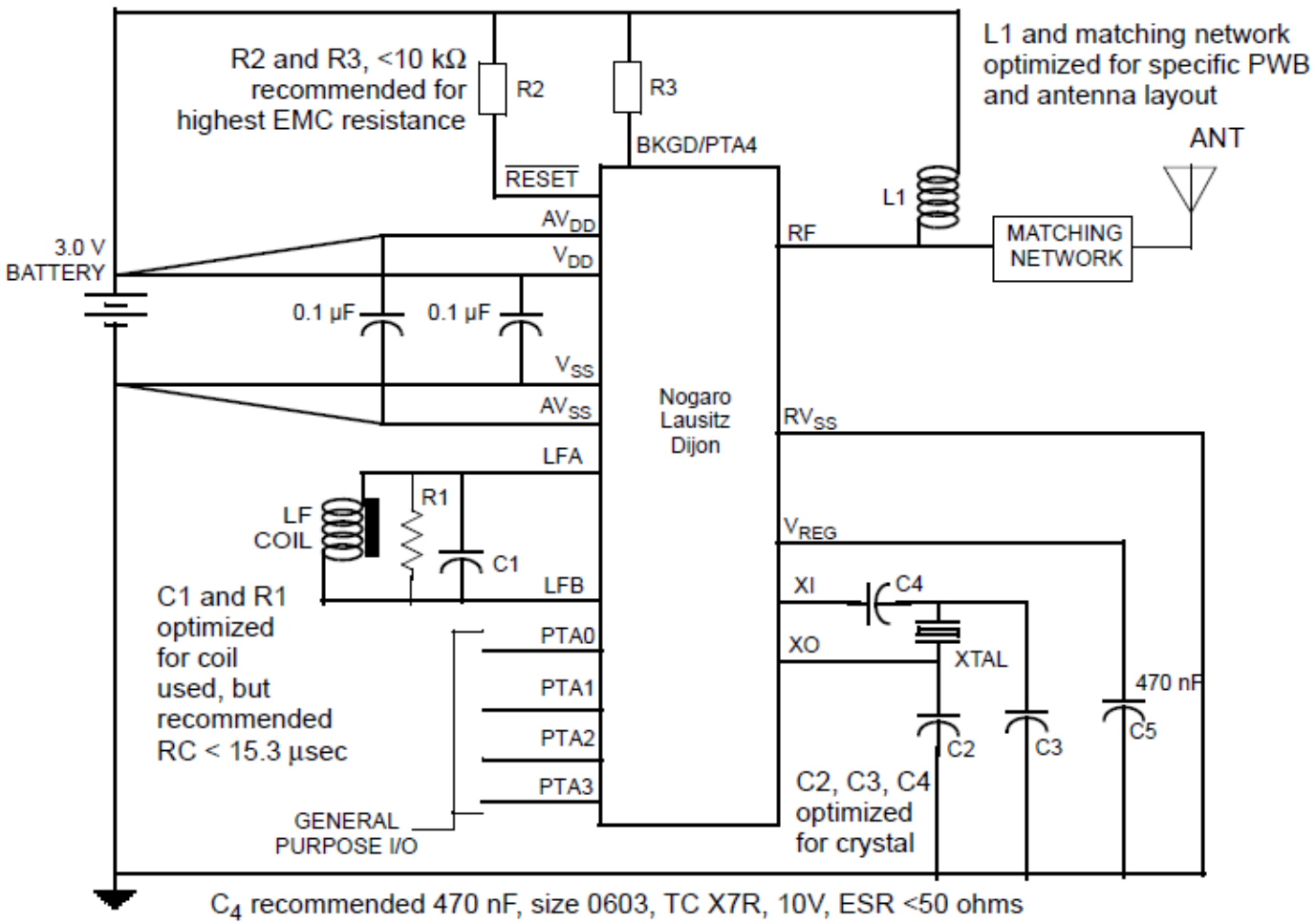
FXTH87 Family Tire Pressure Monitoring System



- **Microcontroller**
  - S08 core, 0.25 um SGF technology
  - **16 kB SGF flash (8 kB firmware, 8 kB customer), 512B RAM, 64 parameter registers**
  - 10 bit ADC, temperature sensor and thermal restart
  - 1-channel LF detector and decoder
  - 8 MHz clock, 2-ch timer, 1 kHz LFO
  - Integrated RF transmitter
  - Frac-N PLL based transmitter, 315/434 MHz
  - FSK/ASK modulation
  - Manchester or bi-phase encoding
  - -1 dBm to +8 dBm output power
- **Pressure Sensor**
  - CMOS capacitive p-cell w/o signal conditioning
- **Acceleration Sensor**
  - Z-axis or dual XZ
- **Package**
  - FAM 7 x 7 mm QFN

- Design Considerations:
  - **RF Tx (7 mA @ 5 dBm)**
  - **LF Rx (4 uA, snif)**
  - **Process Technology – 0.25 um**
  - **Core Type – S08**
  - **Voltage Supplies – 1.8 V to 3.6 V (transmit)**
  - **Voltage Supplies – 2.3 V to 3.6 V (measure)**
  - **Packaging Requirements – Media protection**

FXTH87 Typical Application Schematic



Please refer to product specification for full details

FXTH87 Tire Pressure Monitoring Sensors

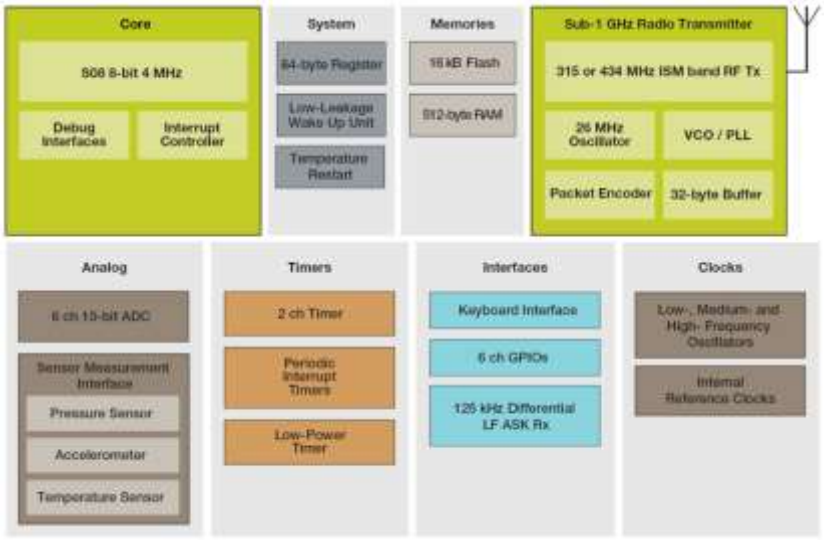
Integrated Tire Pressure Monitoring System (TPMS)

- **Smallest Package Size Single Chip Integration**
  - The compact 7 x 7 x 2.2 mm industry-leading package enables smallest module design for lighter weight applications. Weight : 0.3 gram.
- **Flexibility**
  - Includes an XZ-axis accelerometer that offers customers motion detection and tire localization
  - 512 byte RAM and 8 kB and of customer flash memory gives more application flexibility
- **Robustness / Power**
  - Robust package design with encapsulated inter-chip bond wires
  - Smallest RF transmit battery consumption

Key Benefits

Industry's Smallest Tire Pressure Monitoring System

- Highest level of integration
  - 450/900 kPa pressure sensor
  - 1-/2-axis accelerometer,
  - MCU with 315/434 MHz RF transmitter and LF receiver
- Compact and Light weight
  - 7 x 7 x 2.2 mm, 0.3g
  - Enable smaller and lighter modules
- Single and Dual axis accelerometer
  - Easy after market installation
  - Support all tire localization methods
- 8 kB flash for customer application
  - Enable differentiated module features
- **In Production Now**

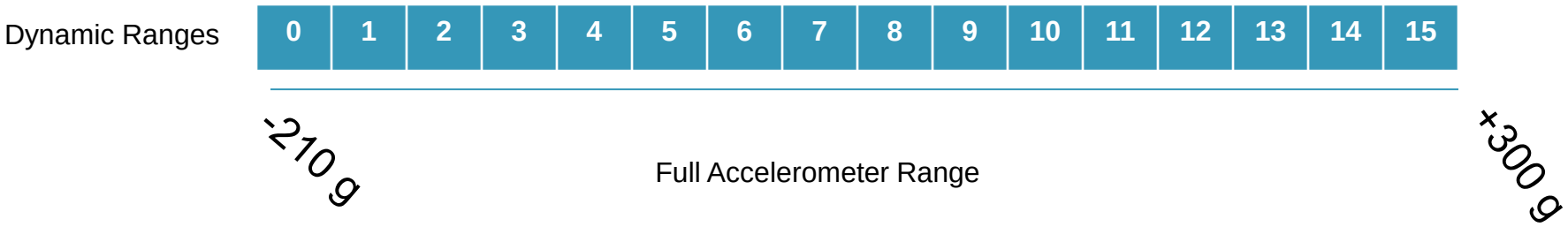


TPMS MCU Power Modes

Variable	RUN	STOP4	STOP1
Active clocks	HFO, MFO, LFO	MFO, LFO	LFO
RAM (512 bytes)	Active	Stand-by	Off
PARAM (64 bytes)	Active	Active	Active
RF Transmitter	Optionally On	Optionally On	Optionally On
LF Receiver	Optionally On	Optionally On	Optionally On
Sensors	Optionally On	Optionally On	Off
MCU	On and clocking	Stand-by, not clocking	Off
PWU	ON	ON	ON
GPIOs	ON	Levels maintained	Hi-Z
Interrupts	Optionally ON	Optionally ON	Some On, Some off, will start code from main()

How to measure +/-1g during high speed tire rotation ?

Use the TPMS_READ_DYNAMIC_ACCEL function



- Freescale Tire Pressure Monitoring Sensors provide the ability to measure -210 up to 300 g by use of sixteen 60 g offsets, each with a resolution of 0.12 g per count
- Ranges overlap by around 250 counts

How to measure +/-1 g during high speed tire rotation ? (2/2)

The TPMS_READ_DYNAMIC_ACCEL function:

- Will sweep through ranges until it finds a useful one
- Will return acceleration for the given range
- Digital output is offset by the range index
  - E.g., a reading of 256 at range index step 6 is 0 g. The same reading with index step 7 is 30 g.

FXTH87 Portfolio (450 kPa- 900 kPa)

Part Number	Pressure range(kPa)	Pressure offset accuracy (0C ≤ Ta ≤ 70C)	Axis of Acceleration	Z-range Sensitivity	Z-offset accuracy	X-range Sensitivity	X-offset accuracy
Standard Tolerances							
FXTH870502**D**T1	100-450	±7 kPa	Z	-270g/+350g 40g sensitivity	±6 g		
FXTH870511**D**T1	100-450	±7 kPa	XZ	-210g/+240g 60g sensitivity	±5 g	-70g/+80g, 10g sensitivity	±4 g
FXTH870902**D**T1	100-900	±10 kPa	Z	-270g/+350g 40g sensitivity	±6 g		
FXTH870911**D**T1	100-900	±10 kPa	XZ	-210g/+240g 60g sensitivity	±5 g	-70g/+80g, 10g sensitivity	±4 g
FXTH870912**D**T1	100-900	±10 kPa	XZ	-270g/+350g 40g sensitivity	±6 g	-70g/+80g, 10g sensitivity	±4 g
Precision Tolerances (Accelerometer)							
FXTH870502**6**T1	100-450	±7 kPa	Z	-270g/+350g 40g sensitivity	±3 g		
FXTH870511**6**T1	100-450	±7 kPa	XZ	-210g/+240g 60g sensitivity	±3 g	-70g/+80g, 10g sensitivity	±3 g
FXTH870902**6**T1	100-900	±10 kPa	Z	-270g/+350g 40g sensitivity	±3 g		
FXTH870911**6**T1	100-900	±10 kPa	XZ	-210g/+240g 60g sensitivity	±3 g	-70g/+80g, 10g sensitivity	±3 g
FXTH870912**6**T1	100-900	±10 kPa	XZ	-270g/+350g 40g sensitivity	±3 g	-70g/+80g, 10g sensitivity	±3 g

- All the products above are in high volume production.
- Fact sheet available on the web. Datasheets available through customer registration

FXTH8715xx 1500kPa Portfolio

Part Number	Pressure range(kPa)	Pressure offset accuracy (0C <= Ta <= 70C)	Axis of Acceleration	Z-range Sensitivity	Z-offset accuracy	X-range	X-offset accuracy
Standard Tolerances							
FXTH871502**D**T1	100-1500	±20 kPa	Z	-270g/+350g, 40g sensitivity	±6 g		
FXTH871511**D**T1	100-1500	±20 kPa	XZ	--210g/+240g, 60g sensitivity	±5 g	-70g/+80g, 10g sensitivity	±4 g
Precision Tolerances							
FXTH8715026T1	100-1500	±20 kPa	Z	-270g/+350g, 40g sensitivity	±3 g		
FXTH8715116T1	100-1500	±20 kPa	XZ	-210g/+240g, 60g sensitivity	±3 g	-70g/+80g, 10g sensitivity	±3 g
High Precision Tolerances							
FXTH8715117T1	100-1500	±17 kPa	XZ	-210g/+240g, 60g sensitivity	±3 g	-70g/+80g, 10g sensitivity	±3 g

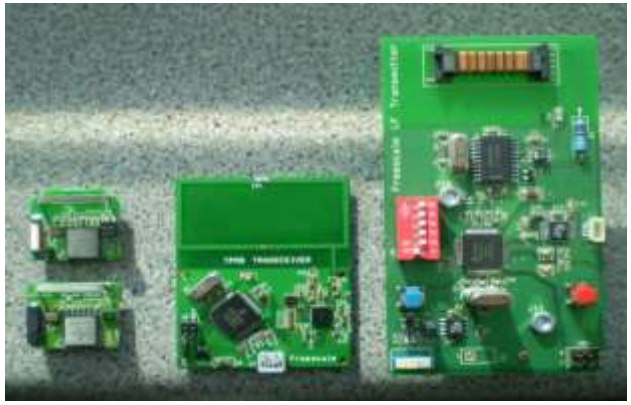
Status

Milestones	450 or 900 kPa Z or XZ version	1500 kPa XZ version
Samples (EV status)	NA	Nov 15, 2014 (*)
Samples (DV status)	In production	Dec 15, 2014
PPAP	Completed June 10th, 2014	Completed Jan 15, 2015
Volume production	High Volume Production	Now
Software Release	**Alpha Version**	**Released Version**
Dual Axis Accelerometer Angular Position Detection	Now to existing customers	End Q4 - 2014
Flexible Flash Library (up to 10 kB user space)	Now to existing customers	End Q4 - 2014
LF Based Flash Boot Loader	Now to existing customers	End Q4 - 2014

FXTH87 Tire Pressure Monitoring Sensor Enablement

Evaluation Boards (EVBs) – emulate typical customer wheel unit module containing FXTH87 sensor, LF coil, RF antenna, battery, and all passives. (Freescale supplied)

TPMS870911-315	(900 kPa – 315 MHz)
TPMS870911-434	(900 kPa – 434 MHz)



- **Application Notes / Reference Manuals** for FXTH87 TPMS family new package and pin out references:
  - FXTH87xx Design Reference Manual (EVB description)
  - FXTH87xx22 Embedded Firmware User Guide (FXTH87XX22FWUG)
  - Interfacing to Freescale's FXTH87xx In-Flash Firmware Routines Using C-language Constructors
  - Using the FXTH87 Family of LF Receivers for TPMS Application (AN4391)
  - Assembly Guidelines for QFN and DFN Packages to cover the QFN 7 x 7 mm package (AN1902)

Strong Customer Adoption

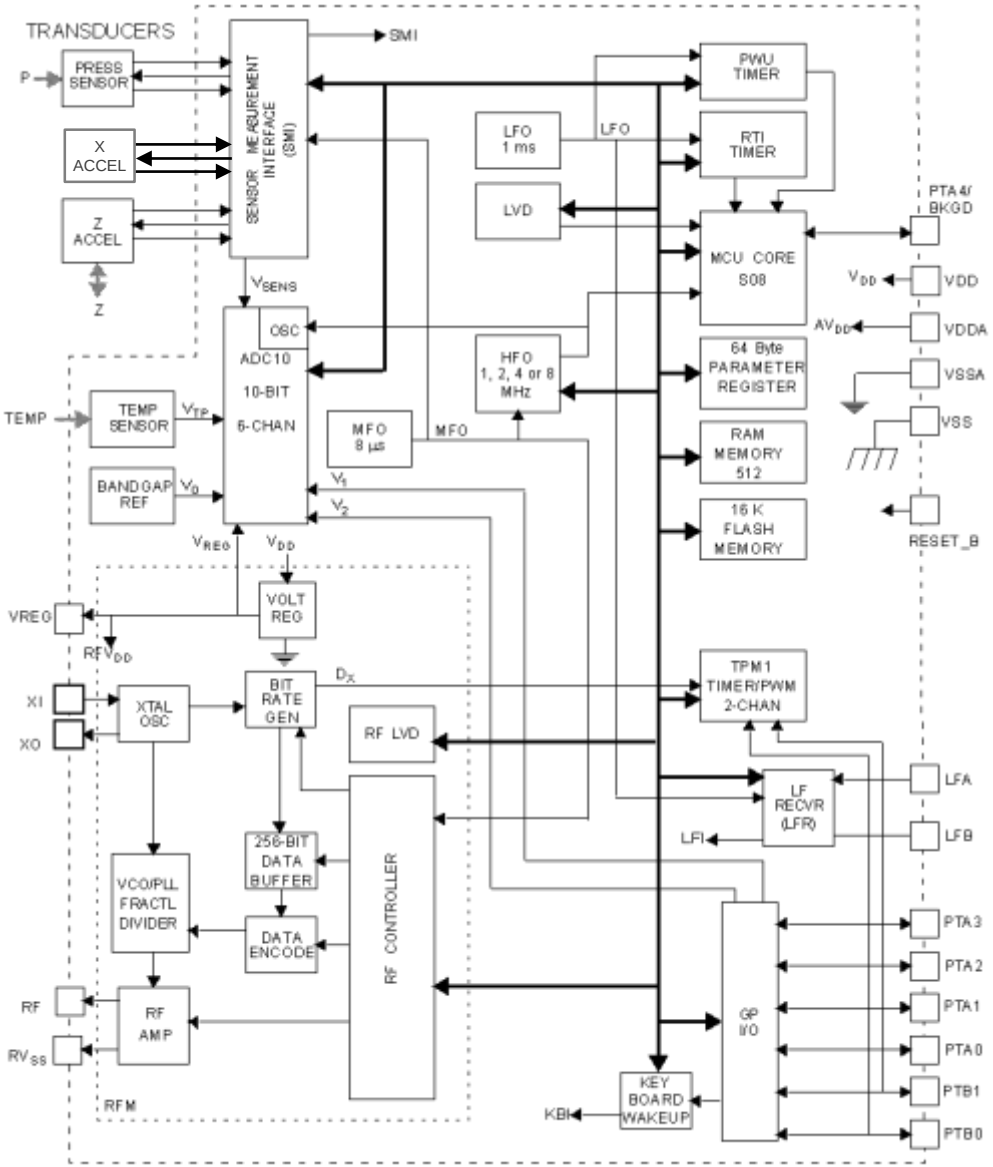
- **Baolong Automotive** introduces world's smallest tire pressure monitoring system
  - New system module leverages the world's smallest tire pressure sensor from Freescale
  - TPMS universal solutions dedicated for both OEM and aftermarket customers
- Baolong Automotive products are shipped to over 80 countries and regions
- Increase vehicle and passenger safety
- Increase fuel efficiency and extend tire life

Make your tires go the distance!

Design Tips

- **RF Design**
- **LF Design**
- **Firmware Sensor Routines**

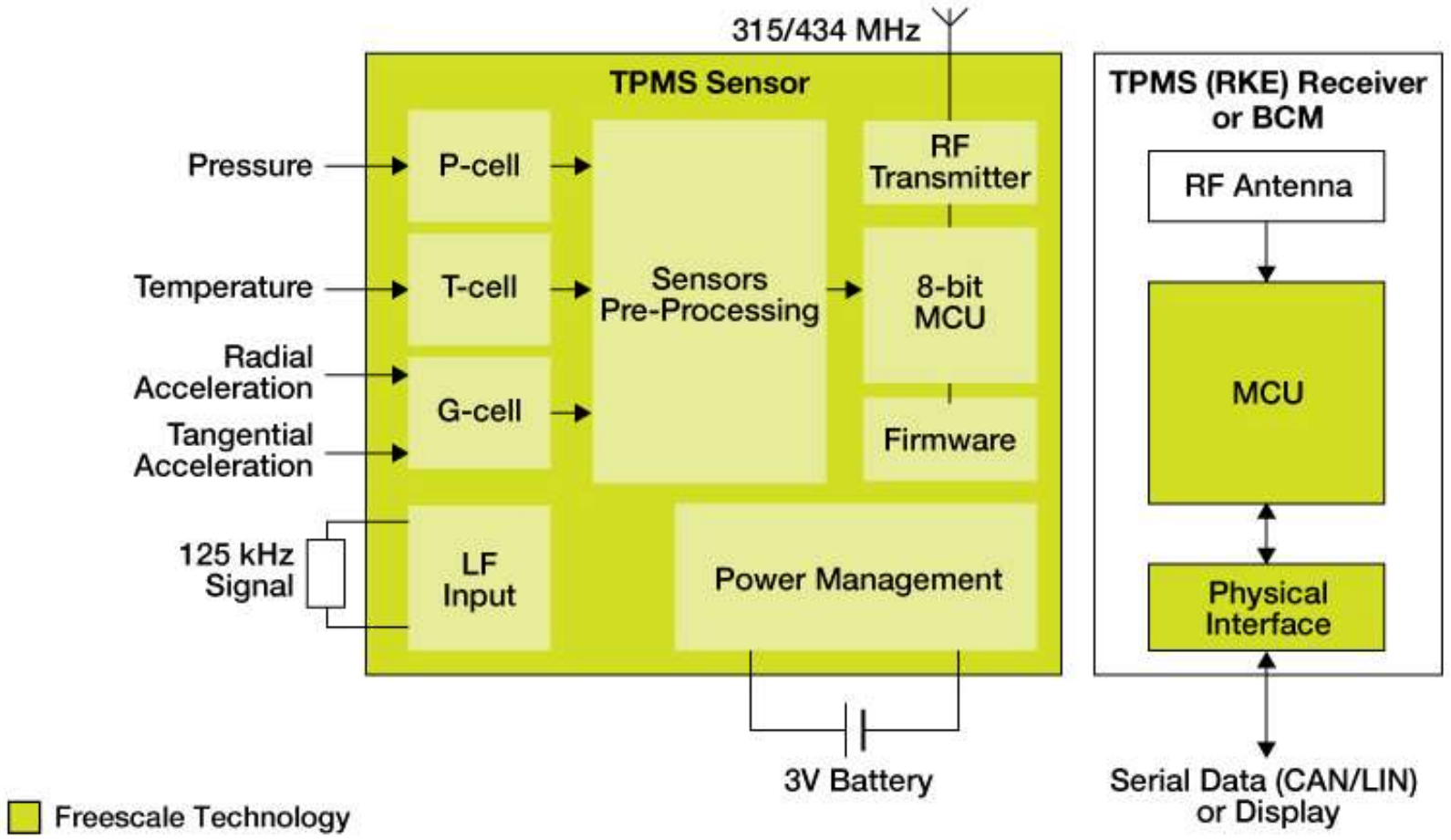
FXTH87 Family Tire Pressure Monitor Sensor



The FXTH87 family has the following features:

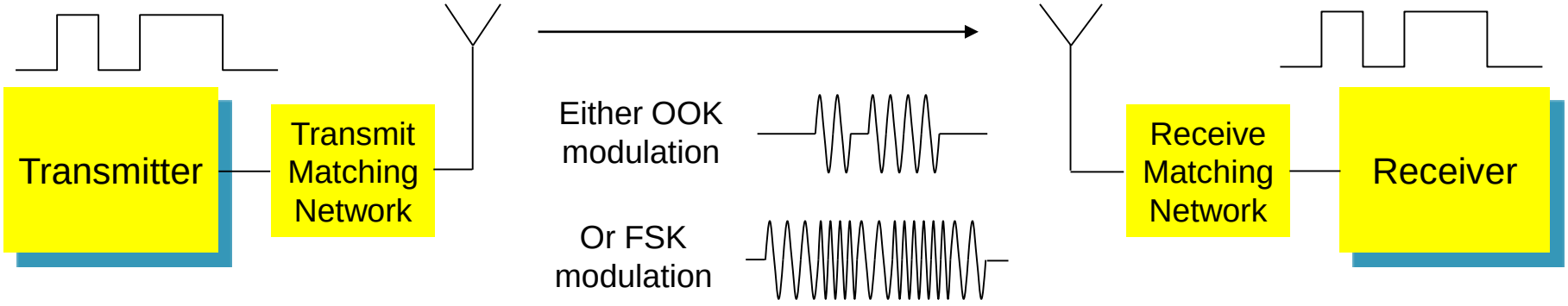
- 8-bit MCU
  - S08 Core with SIM, interrupt and debug/monitor
  - 512 Bytes RAM
  - 16 K Flash (8 K for Freescale library available, 8 K for applications)
  - 64-byte, low power, parameter registers
- Calibrated /compensated temperature, pressure, voltage sensors
- Pressure options: 450, 900, or 1500 kPa ranges
- Accelerometer options: Z-axis or dual XZ-axis
- 10-bit analog-to-digital converter (ADC10)
- Dedicated state machines to sequence routine measurement and transmission processes for reduced power consumption
- Internal 315/434 MHz RF transmitter
  - ASK and FSK modulation capability
  - Programmable data rate generator
  - Manchester, Bi-Phase or NRZ data encoding
  - 256-bit RF data buffer variable length interrupt
- Differential input LF detector/decoder
- 6 Multi-purpose GPIO pins
- Real time interrupt driven by LFO with interrupt intervals of
- 6, 16, 32, 64, 128, 256, 512 or 1024 msec
- Low power wake-up timer and periodic reset driven by LFO
- Watchdog time-out with selectable times and clock sources
- 2-channel general purpose timer/PWM module (TPM1)
- Internal oscillators
- Low voltage detection

Tire Pressure Monitoring System Application Diagram



RF Basics

- The transmitter generates a radio frequency (RF) signal
  - OOK : The signal is canceled during low level
  - FSK : The frequency of the wave varies with the value of the modulating signal
- The transmitter matching network optimize the transfer of power until the antenna
- The transmitter antenna transforms this RF signal to an electromagnetic wave
- The wave propagates to the receiver's antenna
- The receiver antenna collects the wave at RF frequency
- The receiver matching network optimizes the transfer of power until the receiver input
- The receiver processes the signal



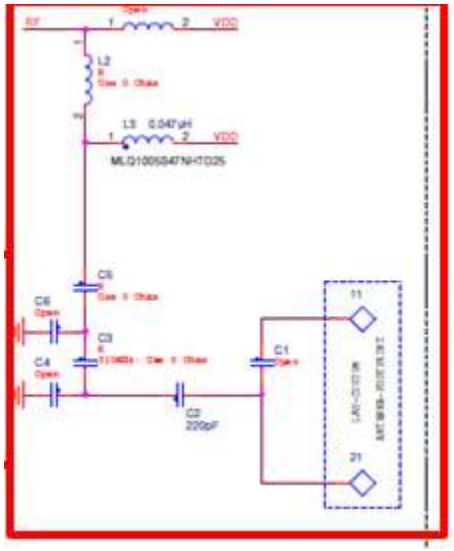
Impedance Locations to be Presented at the RF Pin

315 MHz

Impedance => 88 + j*171

Parallel equivalent => **420 Ohm** // 109 nH (resonating with **2.34pF**)

(Impedance at PA plane, real part only as inductive part at RF pin resonates with internal capacitive component)



(package + bonding + Pad..)

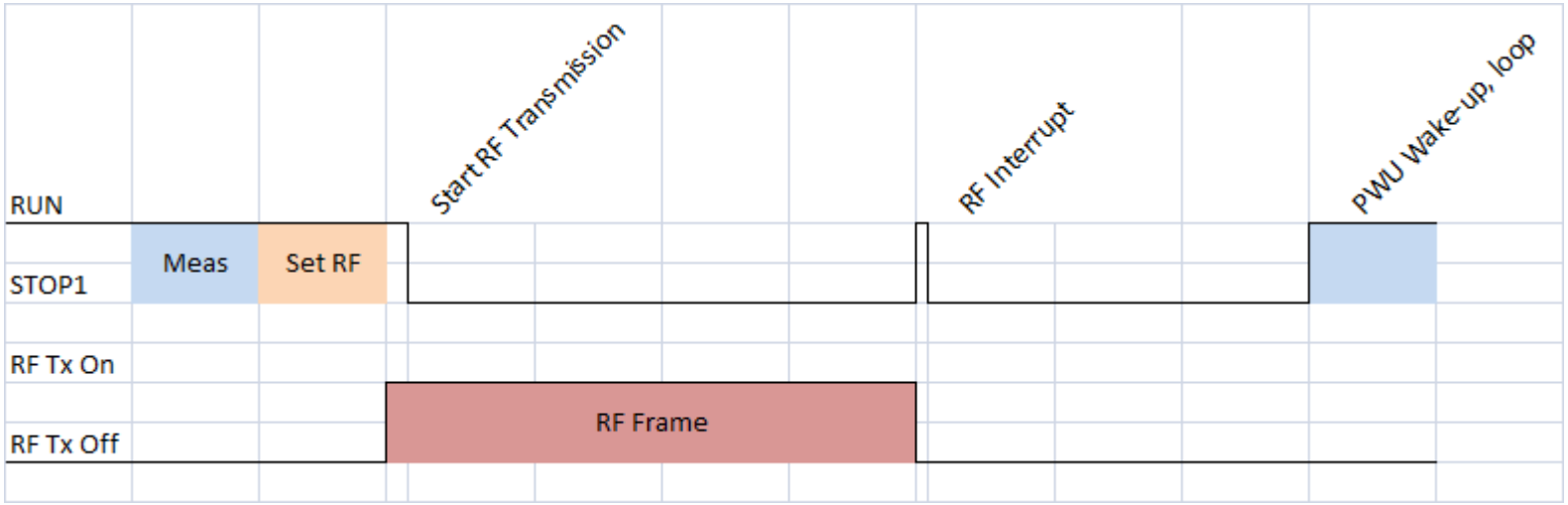
434 MHz

Impedance => 51 + j*137

Parallel equivalent => **415 Ohm** // 57 nH (resonating with **2.35 pF**)

Software

- Sample program in CodeWarrior:



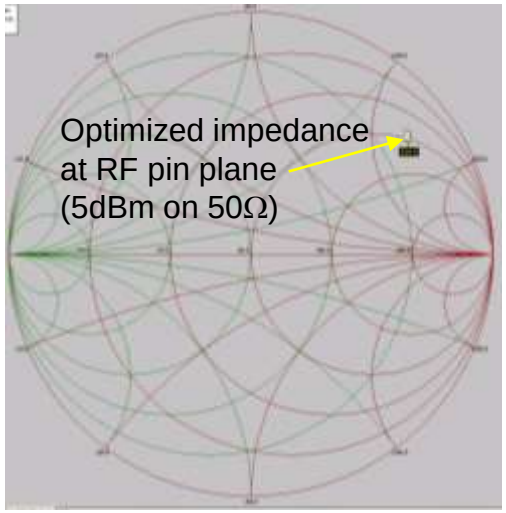
- RF Frame format below:

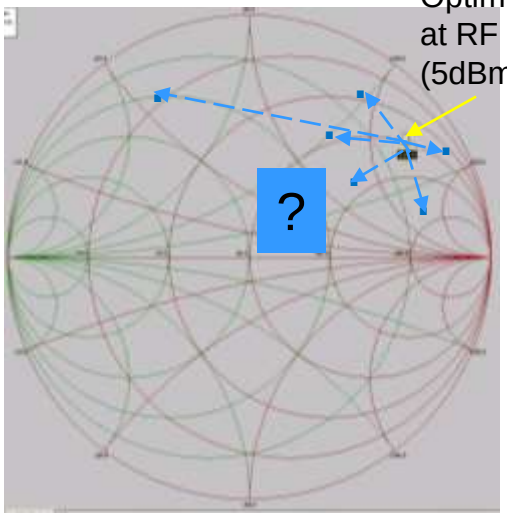
Preamble	Volt	Temp	Press	X-axis	Z-axis	CRC8	Postamble

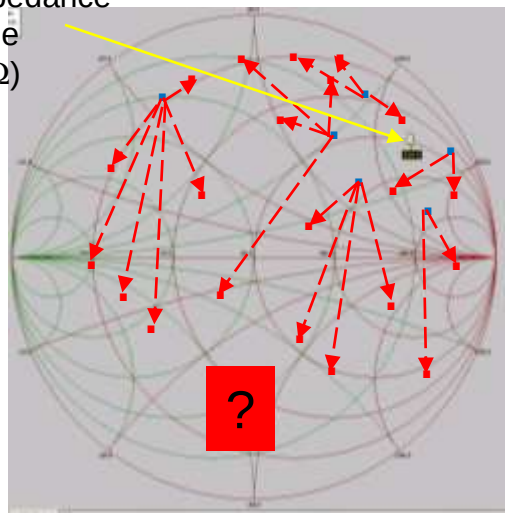
From standalone bare board to final environment (TPMS)

Environment effects on impedance transformation

- Freescale reference board (no media)
- Tier 1 board (housing and PU effects)
- Tier 1 board mounted on RIM (metallic rim and tire effects)



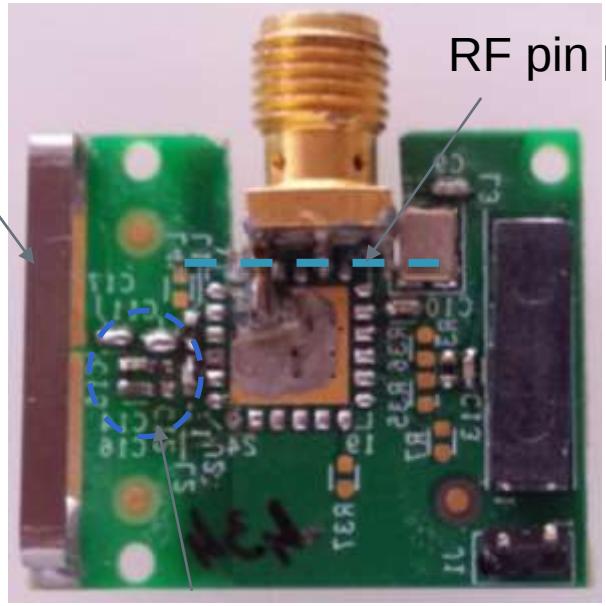




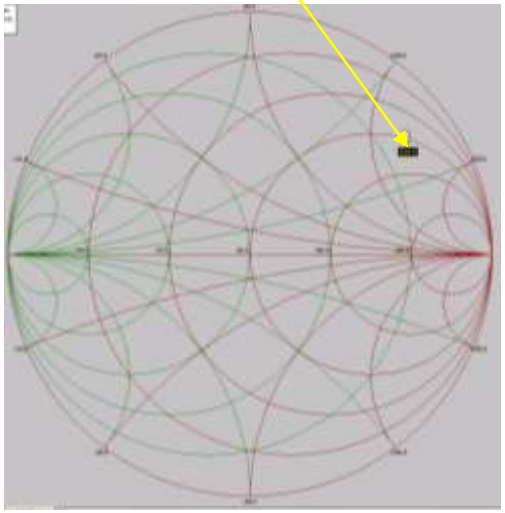
- The matching network must be tuned according to each application (board, PU, housing, rim, etc..) otherwise lost of power. The best would be to finalize matching on module mounted on the rim (but poor accessibility)

Step by step approach - Search optimized impedance on standalone board (1)

- Board standalone (no media, no housing)
- Impedance measurement at RF pin plane is accessible quite easily



Optimized impedance at RF pin plane (5dBm on 50Ω)



- A first matching network is identified, will be fine tuned in final environment
- RF power level is monitored as baseline

Step by step approach - Final tuning in more constraining environment (2)

- Board within its housing and surrounded by PU, RF pin plane tedious to reach

Open areas above matching network components to minimize impedance shifts generated by PU
and housing

- Power level measurement in a « trial and error » process (turn around first matching network values until measuring the same RF power level)

LF Receiver

Carrier Mode

- Amplitude
- frequency
- duration

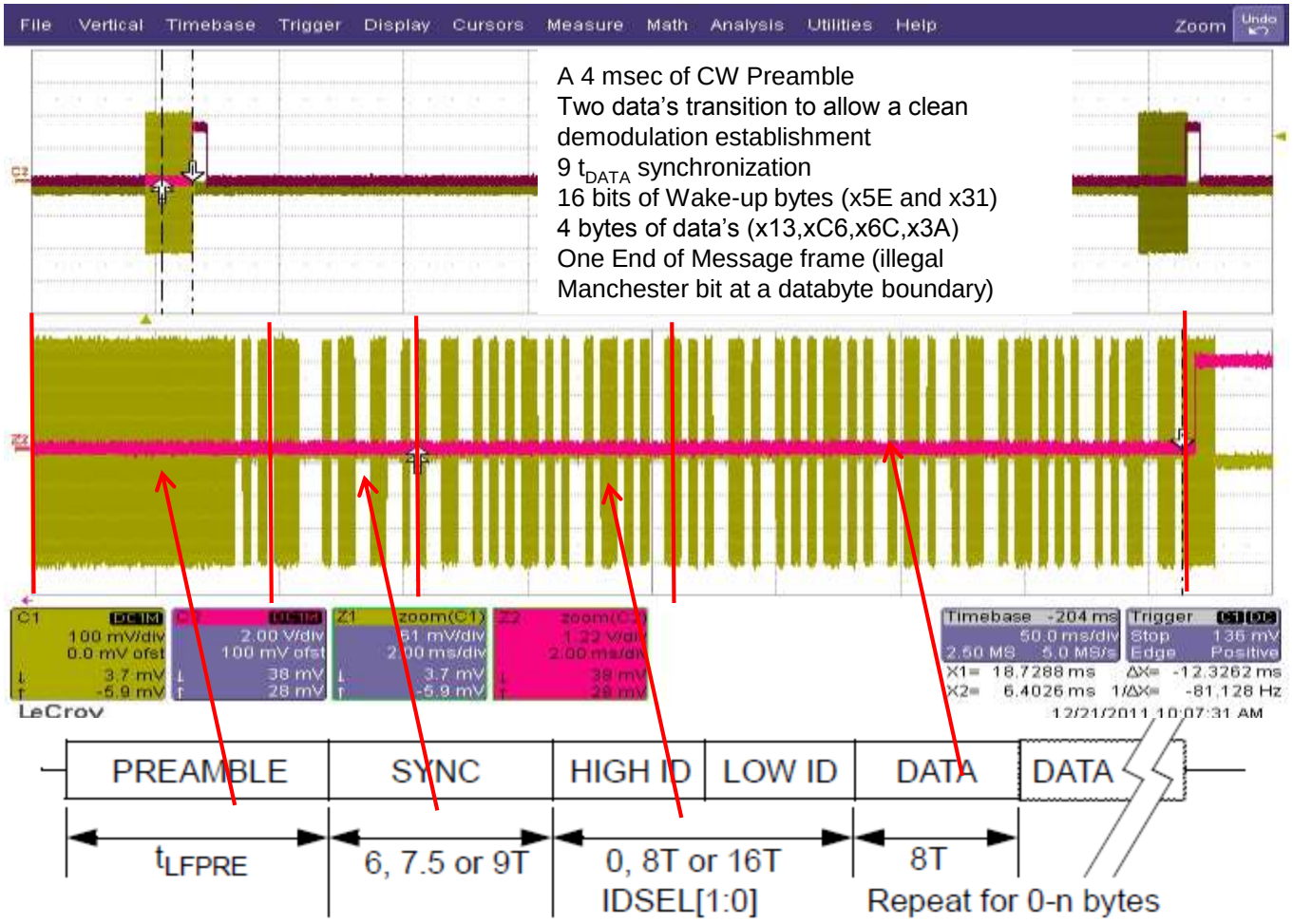
Data Mode

- Carrier Mode + Datagram in Manchester format

Direct Mode

- Data Mode with no Manchester decoding
- Used in rare cases

LF Manchester Datagram



Q-factor Recommendation

- The combination of the external LF antenna and any external components as shown in Figure 12-6 should not significantly filter the envelope of the LF carrier as shown in Figure 12-7. Excessive filtering will cause the received message error rate (MER) to increase.

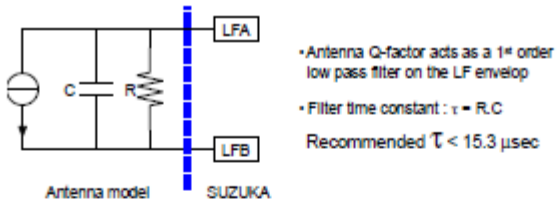


Figure 12-6 Antenna Q-factor Equivalent Model for the LF Envelope

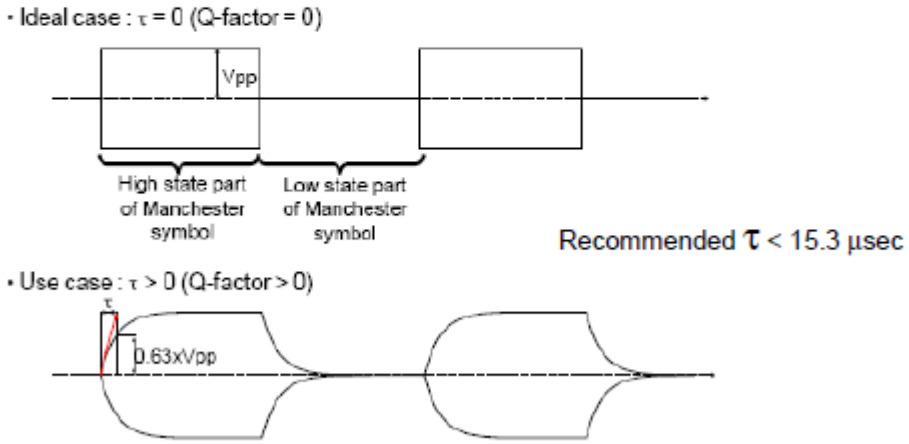
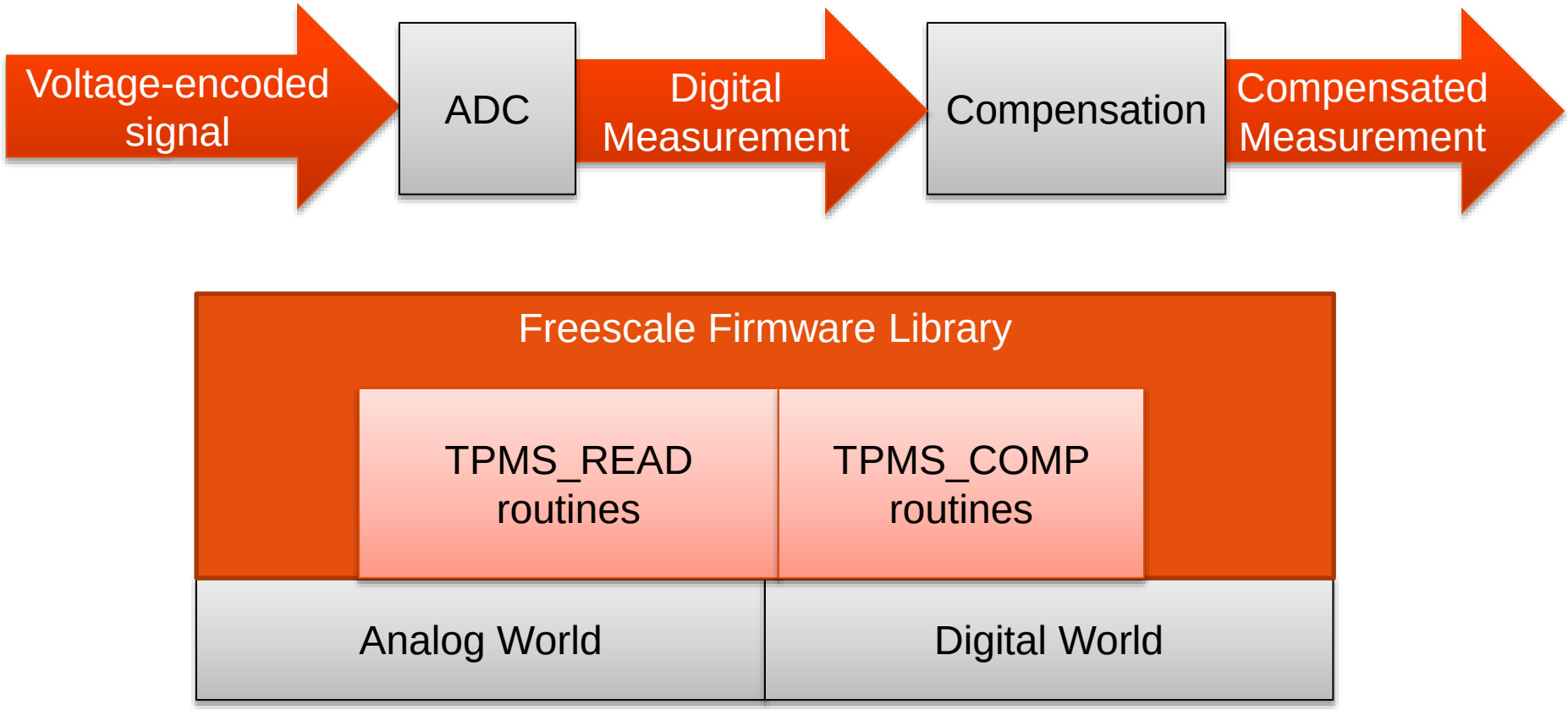


Figure 12-7 LF Envelope Filtering

TPMS MCU Power Modes

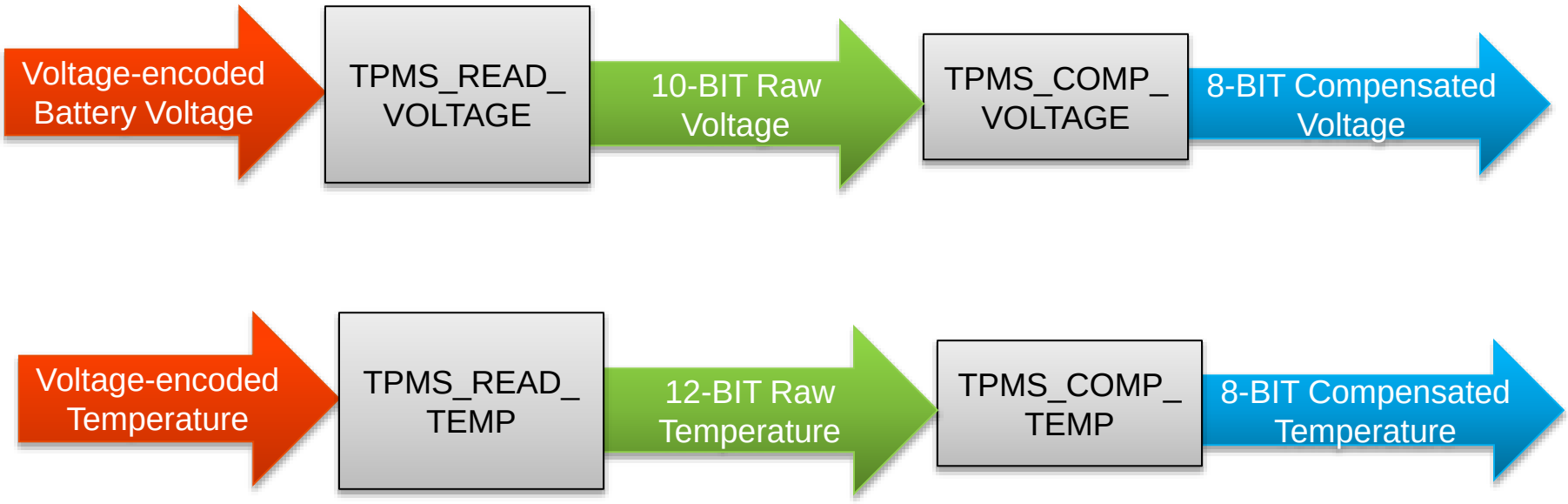
Variable	RUN	STOP4	STOP1
Active clocks	HFO, MFO, LFO	MFO, LFO	LFO
RAM (512 bytes)	Active	Stand-by	Off
PARAM (64 bytes)	Active	Active	Active
RF Transmitter	Optionally On	Optionally On	Optionally On
LF Receiver	Optionally On	Optionally On	Optionally On
Sensors	Optionally On	Optionally On	Off
MCU	On and clocking	Stand-by, not clocking	Off
PWU	ON	ON	ON
GPIOs	ON	Levels maintained	Hi-Z
Interrupts	Optionally ON	Optionally ON	Some On, Some off, will start code from main()

Firmware Sensor Routines



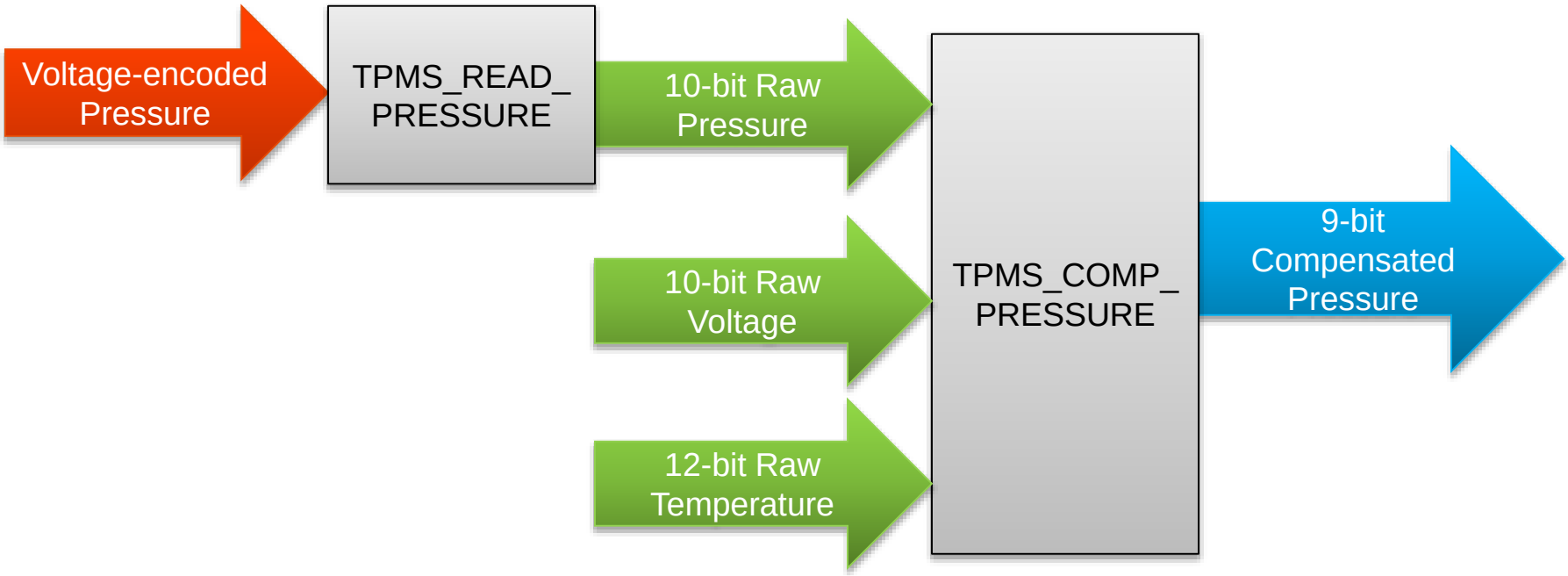
- TPMS_READ routines help acquire raw sensor data
- TPMS_COMP routines linearize raw sensor input

Data Flow for Compensated Measurements (1/3)



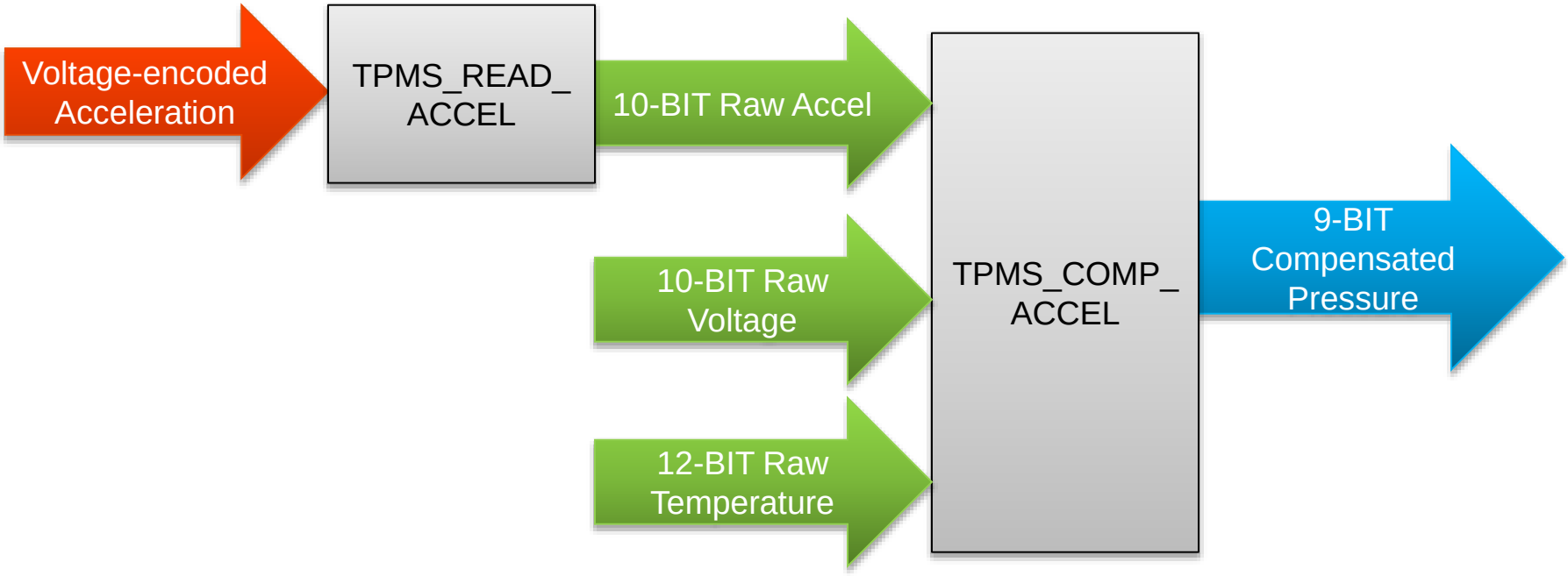
- In this context, compensated means linearized over its own scale

Data Flow for Compensated Measurements (2/3)



- In this context, compensated means linearized over voltage, temperature, and its own scale

Data Flow for Compensated Measurements (3/3)



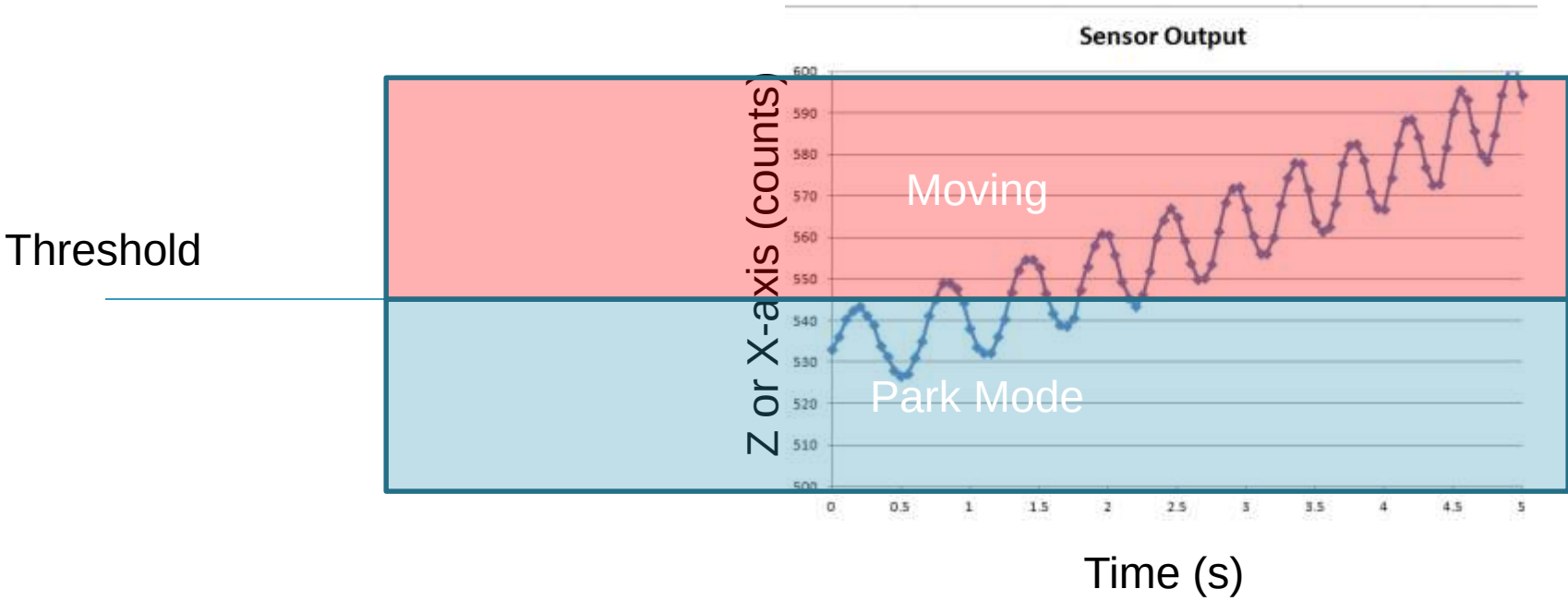
- In this context, compensated means linearized over voltage, temperature, and its own scale

Power-Saving Strategies

- Periodically call TPMS_READ_* routines, but only call TPMS_COMP_* routines if raw values have shifted significantly or if a long period of time has elapsed

- When calling TPMS_COMP_PRESSURE or TPMS_COMP_ACCELERATION, reutilize existing voltage and temperature data instead of requesting new data

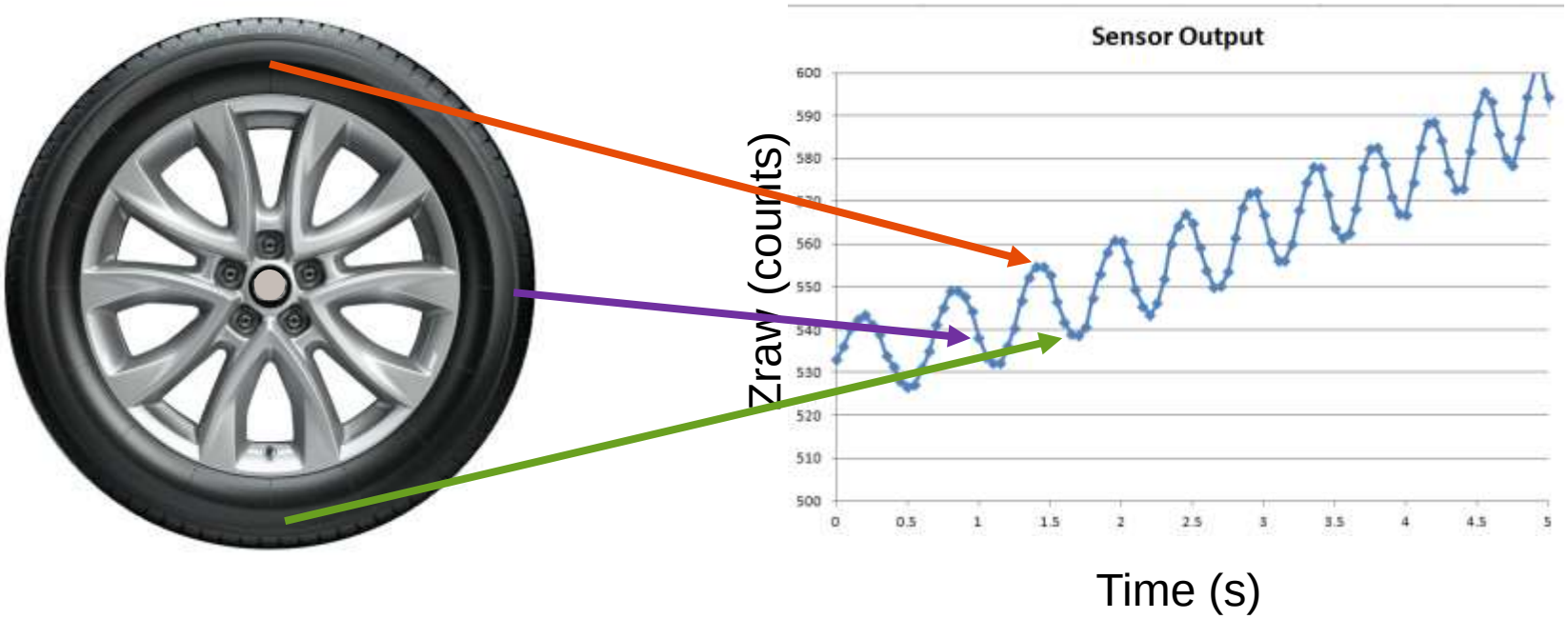
TPMS_READ_ACCEL Functionality



- TPMS_READ_ACCEL and TPMS_COMP_ACCEL are useful when trying to determine whether a vehicle is moving or is stopped

- Choose a threshold to determine if the car is moving, ie if X or Z below threshold, car is stopped and above threshold car is moving.

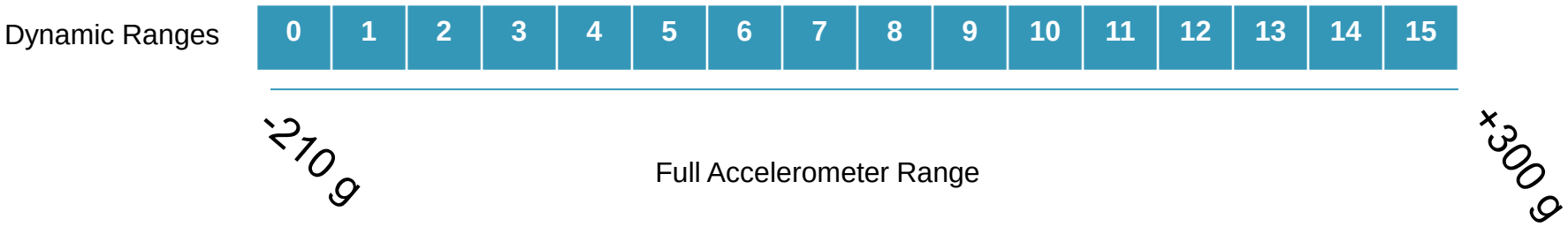
TPMS_READ_ACCEL Functionality



- TPMS_READ_ACCEL can also be used to determine position in the tire
- i.e., each local maximum indicates top-most position in the tire, each local minimum indicates bottom-most position in the tire

How to measure +/-1g during high speed tire rotation ?

Use the TPMS_READ_DYNAMIC_ACCEL function



- Freescale Tire Pressure Monitoring Sensors provide the ability to measure -210 up to 300 g by use of sixteen 60g offsets, each with a resolution of 0.12 g per count.
- Ranges overlap by around 250 counts

How to measure +/-1g during high speed tire rotation ? (2/2)

The TPMS_READ_DYNAMIC_ACCEL function:

- Will sweep through ranges until it finds a useful one
- Will return acceleration for the given range
- Digital output is offset by the range index
  - E.g., a reading of 256 at range index step 6 is 0 g. The same reading with index step 7 is 30 g.

Summary

- TPMS continues to proliferate rapidly through new mandates and regulations
- More emerging markets are being served
- Freescale continuing innovation with world's smallest tire pressure monitoring sensor
- Freescale has been leading sensor innovation for over 35 years

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